

DIELECTRIC PROPERTIES OF HFC 245fa¹

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ABSTRACT

The main objective of this paper is to present dielectric constant data of HFC-245fa (1,1,1,3,3-pentafluoropropane), a liquid hydrofluorocarbon developed as a blowing agent for plastic foams. It is being evaluated as a potential replacement for HCFC-141b. The static dielectric constant of HFC-245fa in the liquid phase was measured using the direct capacitance method at temperatures from 217 to 303 K and under pressures up to 16 MPa. The uncertainty of the measurements is estimated to be within 0.1% and the repeatability of 0.01%. We provide a complete set of tables of experimental data as a function of temperature, pressure and density, which cover dielectric property needs for most engineering applications. The data obtained was correlated by polynomial equations as a function of density and temperature and also as a function of pressure and temperature. In order to study the dependence of dielectric constant on density and temperature in a molecular basis, the theory developed by Vedam et al. and adapted by Diguët was applied to analyse the data. The Kirkwood modification of the Onsager equation was used to obtain the value of its dipole moment in the liquid phase. The apparent dipole moment obtained was $\mu^* = 2.688$ Debye.

KEY WORDS: HFC-245fa, dielectric constant, Kirkwood equation, Vedam equation, dipole moment.

1. INTRODUCTION

The current international agreements addressing global environmental issues (the Montreal and Kyoto Protocols) already provide the guidelines needed to ensure that all refrigerant and blowing agent solutions are environmentally safe. The Montreal Protocol has provided a reasonable, orderly and cost-effective phase-out of all ozone depleting substances. Some HFC blowing agents such as HFC245fa in addition to their superior insulating capability also contribute for the reduction of the total greenhouse gas emission. Allowing for diversity of choice is critical to a successful global policy. Next-generation products are being actively developed and released on the market. Some typical examples are the mixture HFC410A for refrigerants and HFC245fa for foaming. The main application of HFC245fa is as a blowing agent in the building insulation. Foam products used for this purpose include the spray polyurethane foam (SPF) roofing which is used for commercial building roof insulation and the polyisocyanurate (PIR) board stock, which is widely used for building wall and roof insulation.

As indicated in Table 1, the Montreal Protocol phase-out of CFC-11 foam blowing agent was followed by the widespread use of HCFC-141b and cyclopentane. HCFC-141b has one of the highest ODP values among the transitional alternatives, and has been put on an earlier phase-out schedule than other transitional alternatives. The changeover from HCFC-141b to a non-ozone depleting HFC is currently in process, with full-scale production a few years off. The HFC blowing agents with the best thermal performance (e.g., HFC-245fa, HFC-365mfc) result in foams having thermal conductivity comparable to HCFC-141b foams and about 10% lower than cyclopentane blown foam ⁷.

2. EXPERIMENTAL

The measurements were carried out using the direct capacitance method. The description of the cell has been presented before by Mardolcar et al.⁸ and the sample handling, vacuum and pressure system by Gurova et al.⁹ The measuring process involves fully automated instrumentation ¹⁰. Vacuum capacitance was measured before filling the cell with the fluid. An impedance gain-phase analyzer (Shlumberger, model SI 1260) has been used with an

accuracy of 5×10^{-4} pF. The schematic diagram of the apparatus setup for the measurements of the dielectric constant (ϵ) in the liquid phase is presented in Figure 1.

Allied Signal Fluorochemical, Italy has produced the sample used with an estimated purity of 99.9%. Its purity state and physical properties can be seen in Table 2. The supplier provided these data. The fluid was measured without further purification. The measurements were performed at an average of 10 isotherms separated by ≈ 10 K, in steps of 1 MPa, from 1 to 16 MPa. The density values of HFC-245fa were calculated using the REFPROP database, version 6.01, proposed by McLinden et al.¹¹, which has a range of applicability from 200 to 500 K and pressures to 60 MPa.

3. Results

The following relation was used to determine the dielectric constant of the fluid:

$$\epsilon = \frac{C(p, T)}{C_0(T)} \quad (1)$$

where $C(p, T)$ is the geometric capacitance at pressure p and temperature T and $C_0(T)$ is the capacitance under vacuum at a temperature T . No correction for the volumetric effect, due to the pressure, was applied because the cell is subjected to an hydrostatic pressure and so there is no volumetric change. Table 3 presents the data obtained as a function of pressure and density for each isotherm, for the fluid studied. T_n is a nominal temperature. All the experimental points measured at a given temperature T , close to T_n , were adjusted to this temperature, by using:

$$\epsilon(T_n, p) = \epsilon(T, p) + \left(\frac{\partial \epsilon}{\partial T} \right)_p (T_n - T) \quad (2)$$

Figure 2 shows the variation of the dielectric constant with pressure and temperature, for all the isotherms. In figure 3 we can see the graphical representation of dielectric constant as a function of density.

The experimental data of the dielectric constant was fitted by an iterative χ^2 method (each iteration implemented by a Levenberg-Marquart procedure) to a function in density and temperature, of the following form (T in K and ρ in kg m^{-3}):

$$\varepsilon(\rho, T) = \frac{a_1}{T} + a_2 \rho + \frac{a_3 \rho}{T} \quad (3)$$

The coefficients of this fit and their uncertainty can be seen in table 4. The standard deviation of the fit is 0.07%. For industrial needs the data was also fitted to a function in pressure and temperature according to the equation (p in MPa and T in K):

$$\varepsilon(p, T) = b_0 + \frac{b_1}{T} + b_2 p + \frac{b_3 p}{T} \quad (4)$$

These coefficients and their uncertainty are given in Table 4. The standard deviation of the fit is 0.25%.

As a continuation of our previous work ^{1, 10, 13, 14}, we have studied the dependence of the dielectric constant on density applying the concept of Eulerian deformation, also named Eulerian strain, based on the work of Vedam et al.^{2,3} and Diguet ⁴. The theory shows that the variation of the dielectric constant with pressure is a function of the deformation of the volume, showing a non-linear behaviour in the case of liquids. It is possible to reduce this nonlinearity when the variation of ε , Δ , is analysed as a function of the Eulerian deformation, Σ . We can verify that Σ provides a linear relation for Δ independently of the type of molecules that composes the fluid. We have used the relation between $\varepsilon^{1/2}$ and the Eulerian strain, Σ which is defined, according to the Vedam relation, as:

$$\Delta = \varepsilon^{1/2}(\rho) - \varepsilon^{1/2}(\rho_0) = A\Sigma + B \quad (5)$$

$$\Sigma = \frac{1}{2} \left[\left(1 - \frac{\rho}{\rho_0} \right)^{2/3} \right] \quad (6)$$

Here ρ_0 is the reference density, taken in this case as the saturation value for each isotherm. The saturation density data of R245fa was calculated using the equation of state provided by D. Defibaugh and M. Moldover¹² and implemented in the REFPROP Database¹¹.

The calculations show that the function Δ indeed represents a linear variation with the Eulerian Strain Σ , as can be seen in figure 4. Table 5 presents the values of the coefficients A and B of the Vedam equation for each isotherm. The y-crossing values are close to zero for all isotherms, $B \cong 0$. The slope of the linear variation of Δ with Σ is negative for all temperatures, decreasing linearly with the increase with temperature, as expected from the theory. Assuming that $B = 0$ (eq.5) it is possible to use the Vedam relation to estimate the dielectric constant values. We have estimated the new value of A' , by fitting the experimental results as a function of Σ and forcing the constant B to be equal to zero. In this case the Vedam equation takes the following form:

$$\Delta = A' \Sigma \quad (7)$$

The new values of the slope A' according to eq.7 are also presented in Table 5. We can estimate the variation of the dielectric constant with density for each isotherm. Figure 5 presents the deviations between the estimated values and the experimental data of dielectric constant calculated according to this model. As can be seen they are smaller than 0.25%.

In the present work, the apparent dipole moment of HFC-245fa in the liquid phase, was estimated applying the theory of molecular polarizability developed by Kirkwood⁵ based on the definition of Onsager's local field⁶. The dielectric constant of a polar fluid can be related to the apparent dipole moment μ^* through the equation:

$$\frac{(\epsilon - 1)(2\epsilon + 1)}{9\epsilon} \left(\frac{M}{\rho} \right) = \frac{N_0}{3} \left[\alpha + \frac{(\mu^*)^2}{3\epsilon_0 k_B T} \right] \quad (8)$$

Here M is the relative molar mass of the fluid, N_0 is the Avogadro Number, α is the molecular polarizability of the molecule, ϵ_0 the electric permittivity in vacuum, T the absolute temperature and k_B the Boltzmann constant. The apparent dipole moment is

$\mu^* = g^{1/2} \mu$, where μ is the dipole moment in the ideal gas state and g is the Kirkwood correlation parameter that measures the restriction to rotation imposed by a cage of molecules surrounding a given one. By performing a linear regression of the Kirkwood relation as a function of $1/T$ the value of μ^* can be evaluated. Figure 6 shows the plot of the Kirkwood function vs. $1/T$ for HFC-245fa and the value of the apparent dipole moment $\mu^* = 2.688$ Debye (D). Using the value of the dipole moment ($\mu = 1.549$ D) in the gas phase¹¹, the value of the Kirkwood parameter g was found to be equal to 3.01.

4. CONCLUSIONS

The relative permittivity of environmentally acceptable blowing agent for rigid insulating foams HFC-245fa has been measured in the liquid phase. It is being studied as a potential replacement fluid for HCFC-141, partially due to its environmental properties (zero Ozone Depletion Potential and low Global Warming Potential). Our paper presents accurate dielectric constant measurements in the temperature range 218-303 K and pressure from 1 to 16 MPa. The uncertainty of the measurements is estimated to be within 0.1% and the repeatability 0.01%.

The experimental values were correlated as a function of density and temperature and as a function of pressure and temperature, generating two different dielectric equations of state for this fluid.

We have applied the Eulerian formalism to analyse the data, concluding that it represents a successful estimation method for the dependence of the dielectric constant with density.

The Kirkwood function allows a direct determination of the value of the apparent dipole moment μ^* , found to be 2.688 Debye. This theory was also applied to calculate the Kirkwood correlation factor, g , which is equal to 3.01.

When compared with the previous study of HFC-125¹⁵ ($g = 2.52$), it is possible to conclude that for HFC-245fa there is a more restricted rotation of the molecule in the liquid state due to the surrounding molecules^{1,15-17}, a fact that is quantified by the bigger value of the parameter g . Comparison with previous works by the authors also show that HFC-245fa as more restricted rotation in the liquid state than HFC-123, HCFC-141b, HCFC-142b, HFC-143a and HFC-152a¹⁷. This fact can possibly be explained by the fact that the C₃ molecule assuming a *trans* conformation in the liquid state.

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List of symbols

Greek symbols

α - polarizability

χ^2 – iterative method

ε - dielectric constant (electric permittivity) of the liquid

ε_0 - dielectric constant (electric permittivity) in vacuum

ρ - density

ρ_0 - reference density

μ - dipole moment in the gaseous phase

μ^* - apparent dipole moment in the liquid phase

Δ - defined by eq. (5)

Σ - Eulerian strain

Roman symbols

a_i - coefficients of eq. (3)

b_i – coefficients of eq. (4)

g - Kirkwood factor

k_B – Boltzmann constant

p – pressure

A, B – coefficients of eq. (5)

A' – coefficient of eq. (7)

C – geometric capacitance of the cell filled with the liquid

C_0 - geometric capacitance of the cell in vacuum

N_0 – Avogadro number

T – absolute temperature

Table 1. Foam Blowing Agent Alternative

Foam Type	Function	Pre-Montreal Protocol (before 1996)	Transitional (1996-2005)	Non-Ozone Depleting (2003 and beyond)
▪ SPF	Blowing Agent	CFC-11	HCFC-141b	HFC-245fa
▪ PIR Board Stock				HFC-365mfc

Table 2. Physical properties and purity of HFC-245fa

Chemical name	1,1,1,3,3 -Pentafluoropropane
ASHRAE Nomenclature	R-245fa
Molecular formula	$\text{CF}_3\text{CH}_2\text{CHF}_2$
Relative Molar Mass (g/mol)	134.05
Boiling point @ 1atm (°C)	15.3
Estimated water content / ppm	33.5
Free acid (HCl) / ppm	0.19
Purity (wt %)	99.9

Table 3. Experimental values of the dielectric constant of HFC-245fa

T / K	P / MPa	ρ / kgm^{-3}	$\varepsilon(T, p)$	$\rho(T_n, p) / \text{kgm}^{-3}$	$\varepsilon(T_n, p)$	T / K	P / MPa	ρ / kgm^{-3}	$\varepsilon(T, p)$	$\rho(T_n, p) / \text{kgm}^{-3}$	$\varepsilon(T_n, p)$
$T_n = 302.84 \text{ K}$						$T_n = 253.01 \text{ K}$					
302.83	16.00	1370.84	6.7895	1370.81	6.7893	253.01	16.00	1481.03	8.7395	1481.03	8.7395
302.82	15.00	1368.39	6.7698	1368.34	6.7694	253.01	15.00	1479.43	8.7250	1479.43	8.7250
302.82	14.00	1365.88	6.7500	1365.84	6.7497	253.01	14.00	1477.81	8.7112	1477.81	8.7112
302.82	13.00	1363.33	6.7295	1363.29	6.7292	253.01	13.00	1476.19	8.6948	1476.19	8.6948
302.82	12.00	1360.74	6.7093	1360.69	6.7090	253.01	12.00	1474.54	8.6775	1474.54	8.6775
302.82	11.00	1358.10	6.6886	1358.05	6.6883	253.01	11.00	1472.88	8.6605	1472.88	8.6605
302.82	10.00	1355.41	6.6679	1355.37	6.6676	253.01	10.00	1471.21	8.6436	1471.21	8.6436
302.82	9.00	1352.68	6.6465	1352.63	6.6462	253.00	9.00	1469.54	8.6255	1469.52	8.6253
302.82	8.00	1349.89	6.6244	1349.84	6.6241	253.01	8.00	1467.82	8.6081	1467.82	8.6081
302.82	7.00	1347.05	6.6024	1347.00	6.6020	253.01	7.00	1466.09	8.5911	1466.09	8.5911
302.82	6.00	1344.15	6.5801	1344.10	6.5798	253.00	6.00	1464.38	8.5719	1464.36	8.5717
302.82	5.00	1341.20	6.5576	1341.14	6.5572	253.01	5.00	1462.60	8.5529	1462.60	8.5529
302.82	4.00	1338.18	6.5336	1338.13	6.5333	253.02	4.00	1460.81	8.5354	1460.83	8.5357
302.82	3.00	1335.09	6.5107	1335.04	6.5104	253.01	3.00	1459.04	8.5171	1459.04	8.5171
302.82	2.00	1331.94	6.4860	1331.89	6.4857	253.01	2.00	1457.23	8.4986	1457.23	8.4986
303.13	1.00	1327.86	6.4496	1328.66	6.4544	253.01	1.00	1455.41	8.4798	1455.41	8.4798
$T_n = 293.23 \text{ K}$						$T_n = 243.02 \text{ K}$					
293.23	16.00	1392.66	7.1302	1392.66	7.1302	243.03	16.00	1502.23	9.2058	1502.25	9.2060
293.22	15.00	1390.41	7.1113	1390.39	7.1112	243.03	15.00	1500.77	9.1895	1500.79	9.1897
293.23	14.00	1388.09	7.0921	1388.09	7.0921	243.02	14.00	1499.32	9.1731	1499.32	9.1731
293.23	13.00	1385.76	7.0734	1385.76	7.0734	243.02	13.00	1497.83	9.1567	1497.83	9.1567
293.22	12.00	1383.41	7.0539	1383.39	7.0537	243.02	12.00	1496.34	9.1399	1496.34	9.1399
293.23	11.00	1380.98	7.0337	1380.98	7.0337	243.02	11.00	1494.83	9.1247	1494.83	9.1247
293.23	10.00	1378.54	7.0135	1378.54	7.0135	243.02	10.00	1493.31	9.1110	1493.31	9.1110
293.23	9.00	1376.05	6.9932	1376.05	6.9932	243.02	9.00	1491.77	9.0949	1491.77	9.0949
293.22	8.00	1373.55	6.9727	1373.53	6.9725	243.02	8.00	1490.23	9.0781	1490.23	9.0781
293.22	7.00	1370.99	6.9518	1370.96	6.9516	243.02	7.00	1488.67	9.0610	1488.67	9.0610
293.22	6.00	1368.37	6.9303	1368.35	6.9302	243.02	6.00	1487.10	9.0438	1487.10	9.0438
293.22	5.00	1365.72	6.9094	1365.69	6.9092	243.02	5.00	1485.51	9.0259	1485.51	9.0259
293.22	4.00	1363.01	6.8873	1362.99	6.8871	243.02	4.00	1483.91	9.0085	1483.91	9.0085
293.22	3.00	1360.26	6.8641	1360.23	6.8639	243.02	3.00	1482.30	8.9907	1482.30	8.9907

293.22	2.00	1357.45	6.8433	1357.42	6.8431	243.02	2.00	1480.68	8.9728	1480.68	8.9728
293.24	1.00	1354.53	6.8154	1354.56	6.8156	243.02	1.00	1479.04	8.9552	1479.04	8.9552
$T_n = 283.19$ K						$T_n = 233.12$ K					
283.20	16.00	1415.14	7.5012	1415.16	7.5014	233.14	16.00	1522.97	9.7015	1523.01	9.7021
283.20	15.00	1413.07	7.4832	1413.09	7.4833	233.14	15.00	1521.64	9.6858	1521.68	9.6864
283.19	14.00	1410.98	7.4648	1410.98	7.4648	233.13	14.00	1520.32	9.6695	1520.34	9.6698
283.19	13.00	1408.85	7.4464	1408.85	7.4464	233.13	13.00	1518.97	9.6543	1518.99	9.6546
283.19	12.00	1406.69	7.4273	1406.69	7.4273	233.13	12.00	1517.61	9.6380	1517.63	9.6383
283.19	11.00	1404.50	7.4086	1404.50	7.4086	233.12	11.00	1516.26	9.6223	1516.26	9.6223
283.19	10.00	1402.28	7.3891	1402.28	7.3891	233.12	10.00	1514.88	9.6055	1514.88	9.6055
283.19	9.00	1400.03	7.3698	1400.03	7.3698	233.12	9.00	1513.49	9.5890	1513.49	9.5890
283.19	8.00	1397.75	7.3498	1397.75	7.3498	233.12	8.00	1512.09	9.5721	1512.09	9.5721
283.18	7.00	1395.45	7.3299	1395.43	7.3297	233.12	7.00	1510.69	9.5564	1510.69	9.5564
283.18	6.00	1393.10	7.3094	1393.08	7.3093	233.11	6.00	1509.29	9.5436	1509.27	9.5433
283.18	5.00	1390.71	7.2891	1390.69	7.2889	233.12	5.00	1507.84	9.5291	1507.84	9.5291
283.18	4.00	1388.29	7.2684	1388.27	7.2682	233.11	4.00	1506.43	9.5117	1506.40	9.5114
283.18	3.00	1385.83	7.2470	1385.80	7.2468	233.11	3.00	1504.98	9.4944	1504.96	9.4941
283.19	2.00	1383.30	7.2258	1383.30	7.2258	233.11	2.00	1503.52	9.4780	1503.50	9.4777
283.19	1.00	1380.76	7.2014	1380.76	7.2014	233.11	1.00	1502.05	9.4607	1502.03	9.4604
$T_n = 273.12$ K						$T_n = 224.16$ K					
273.13	16.00	1437.41	7.8934	1437.43	7.8936	224.15	16.00	1541.58	10.1922	1541.56	10.1919
273.13	15.00	1435.51	7.8747	1435.53	7.8749	224.15	15.00	1540.36	10.1763	1540.34	10.1760
273.13	14.00	1433.58	7.8568	1433.60	7.8570	224.16	14.00	1539.12	10.1602	1539.12	10.1602
273.12	13.00	1431.65	7.8389	1431.65	7.8389	224.16	13.00	1537.89	10.1441	1537.89	10.1441
273.12	12.00	1429.68	7.8207	1429.68	7.8207	224.16	12.00	1536.65	10.1284	1536.65	10.1284
273.12	11.00	1427.69	7.8023	1427.69	7.8023	224.16	11.00	1535.40	10.1123	1535.40	10.1123
273.12	10.00	1425.67	7.7836	1425.67	7.7836	224.16	10.00	1534.15	10.0965	1534.15	10.0965
273.12	9.00	1423.62	7.7649	1423.62	7.7649	224.15	9.00	1532.90	10.0809	1532.88	10.0806
273.12	8.00	1421.55	7.7460	1421.55	7.7460	224.15	8.00	1531.64	10.0643	1531.61	10.0640
273.11	7.00	1419.48	7.7266	1419.46	7.7264	224.15	7.00	1530.36	10.0477	1530.34	10.0474
273.12	6.00	1417.33	7.7073	1417.33	7.7073	224.15	6.00	1529.07	10.0312	1529.05	10.0309
273.12	5.00	1415.18	7.6877	1415.18	7.6877	224.17	5.00	1527.74	10.0137	1527.76	10.0140
273.12	4.00	1413.00	7.6678	1413.00	7.6678	224.17	4.00	1526.44	9.9965	1526.46	9.9968
273.12	3.00	1410.79	7.6478	1410.79	7.6478	224.17	3.00	1525.13	9.9837	1525.15	9.9840
273.12	2.00	1408.55	7.6275	1408.55	7.6275	224.17	2.00	1523.81	9.9673	1523.83	9.9676

273.13	1.00	1406.26	7.6055	1406.28	7.6057	224.17	1.00	1522.49	9.9501	1522.51	9.9504
$T_n = 263.00$ K						$T_n = 218.53$ K					
263.00	16.00	1459.51	8.3091	1459.51	8.3091	218.57	16.00	1553.02	10.5064	1553.10	10.5076
263.00	15.00	1457.77	8.2921	1457.77	8.2921	218.54	15.00	1551.93	10.4929	1551.95	10.4932
263.00	14.00	1456.01	8.2738	1456.01	8.2738	218.54	14.00	1550.78	10.4782	1550.80	10.4785
263.00	13.00	1454.23	8.2566	1454.23	8.2566	218.55	13.00	1549.60	10.4625	1549.64	10.4632
263.00	12.00	1452.43	8.2388	1452.43	8.2388	218.56	12.00	1548.42	10.4461	1548.48	10.4471
263.00	11.00	1450.61	8.2212	1450.61	8.2212	218.59	11.00	1547.18	10.4291	1547.31	10.4310
263.00	10.00	1448.77	8.2030	1448.77	8.2030	218.60	10.00	1545.98	10.4121	1546.13	10.4143
263.00	9.00	1446.91	8.1850	1446.91	8.1850	218.61	9.00	1544.78	10.3955	1544.95	10.3980
263.00	8.00	1445.03	8.1668	1445.03	8.1668	218.61	8.00	1543.58	10.3791	1543.76	10.3816
263.00	7.00	1443.14	8.1481	1443.14	8.1481	218.60	7.00	1542.41	10.3634	1542.56	10.3656
263.00	6.00	1441.22	8.1295	1441.22	8.1295	218.61	6.00	1541.18	10.3474	1541.35	10.3499
263.00	5.00	1439.28	8.1107	1439.28	8.1107	218.54	5.00	1540.12	10.3324	1540.14	10.3327
263.00	4.00	1437.31	8.0917	1437.31	8.0917	218.48	4.00	1539.04	10.3195	1538.93	10.3180
263.00	3.00	1435.33	8.0726	1435.33	8.0726	218.42	3.00	1537.95	10.3072	1537.70	10.3038
263.00	2.00	1433.32	8.0528	1433.32	8.0528	218.34	2.00	1536.90	10.2951	1536.47	10.2891
263.00	1.00	1431.29	8.0335	1431.29	8.0335	218.28	1.00	1535.80	10.2890	1535.24	10.2811

Table 4. Coefficients of the dielectric equations of state (eq.3 and eq.4)

<hr/>			
	a_1 / K	$10^{-3} a_2 / \text{kg}^{-1} \text{ m}^3$	$a_3 / \text{K m}^3 \text{ kg}^{-1}$
	-1505.2 ± 23.5	1.8618 ± 0.0256	2.038 ± 0.0097
<hr/>			
b_0	b_1 / K	$10^{-2} b_2 / \text{MPa}^{-1}$	$b_3 / \text{K MPa}^{-1}$
-3.345 ± 0.037	2980.4 ± 9.51	3.6179 ± 0.387	-4.5909 ± 0.984

Table 5. Values of the constants A and B of the Vedam Equation (eq.5) and A' in eq.7

T_n / K	$\rho_{sat} / \text{kgm}^{-3}$	$\varepsilon(\rho_{sat})$	A	B	A'
302.84	1325.95	6.4224	- 6.090	0.00305	- 6.4771
293.23	1352.00	6.7815	- 6.327	0.00297	- 6.7513
283.19	1378.39	7.1717	- 6.647	0.00201	- 6.9714
273.12	1404.11	7.5814	- 6.986	0.00089	- 7.1471
263.00	1429.30	8.0146	- 7.347	- 0.00015	- 7.3166
253.01	1453.60	8.4670	- 7.643	- 0.00085	- 7.4482
243.02	1477.41	8.9478	- 7.918	- 0.00147	- 7.5386
233.12	1500.56	9.4565	- 8.342	- 0.00212	- 7.7256
224.16	1521.18	9.9487	- 9.152	- 0.00261	- 8.3058
218.53	1534.00	10.2755	- 9.405	- 0.00305	- 8.3408

FIGURE CAPTIONS

Figure 1. Schematic diagram of the apparatus.

Figure 2. Graphical representation of the dielectric constant as a function of pressure, for the different isotherms.

Figure 3. The dielectric constant as a function of density, for the different isotherms.

Figure 4. Variation of Δ with the Eulerian Strain, Σ (eq.5).

Figure 5. Deviations from the experimental data of the dielectric constant values $[(\epsilon_{VR} - \epsilon_{exp}) / \epsilon_{exp} * 100]$, according to the Vedam relation (eq.7).

Figure 6. Kirkwood function vs. $1/T$.

Figure 1. Schematic diagram of the apparatus.

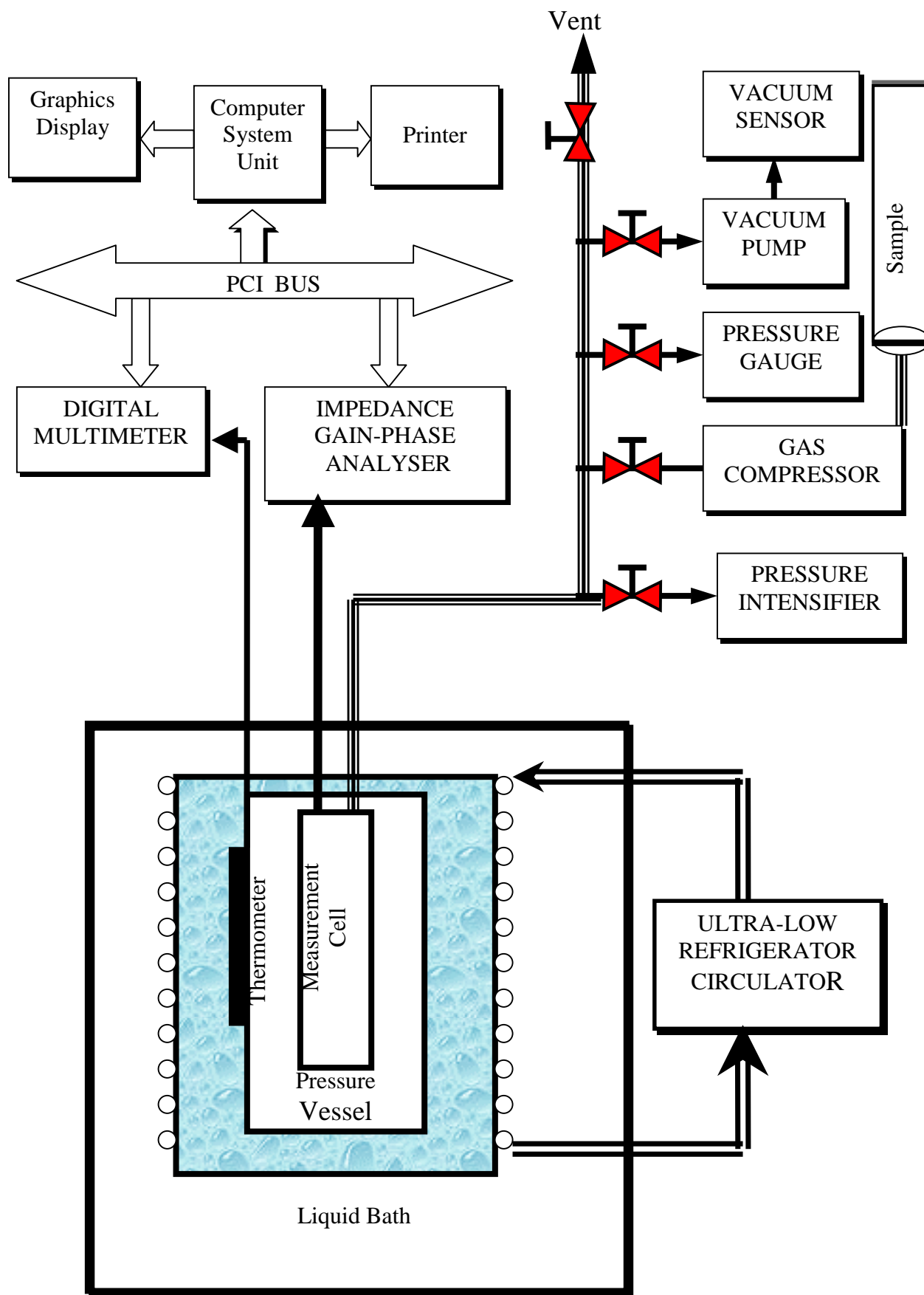


Figure 2. Graphical representation of the dielectric constant as a function of pressure, for the different isotherms.

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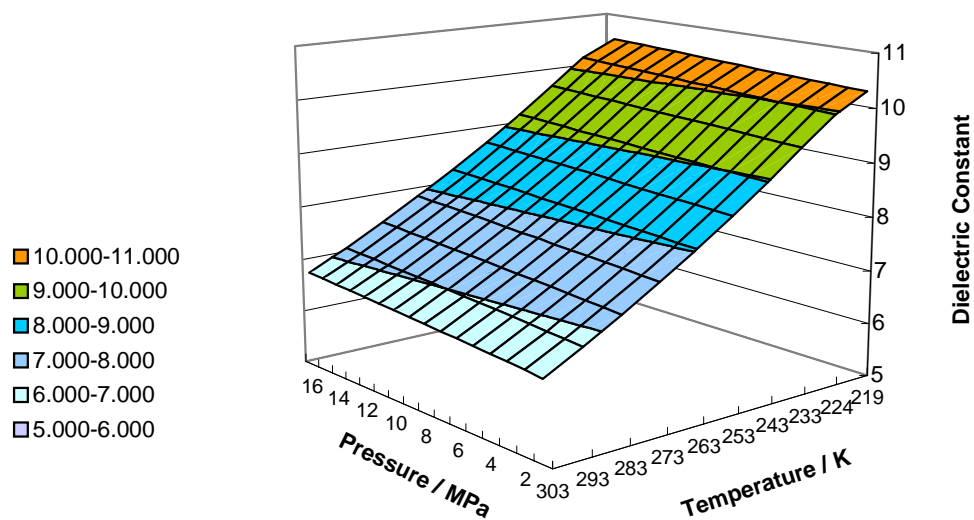


Figure 3. The dielectric constant as a function of density, for different isotherms.

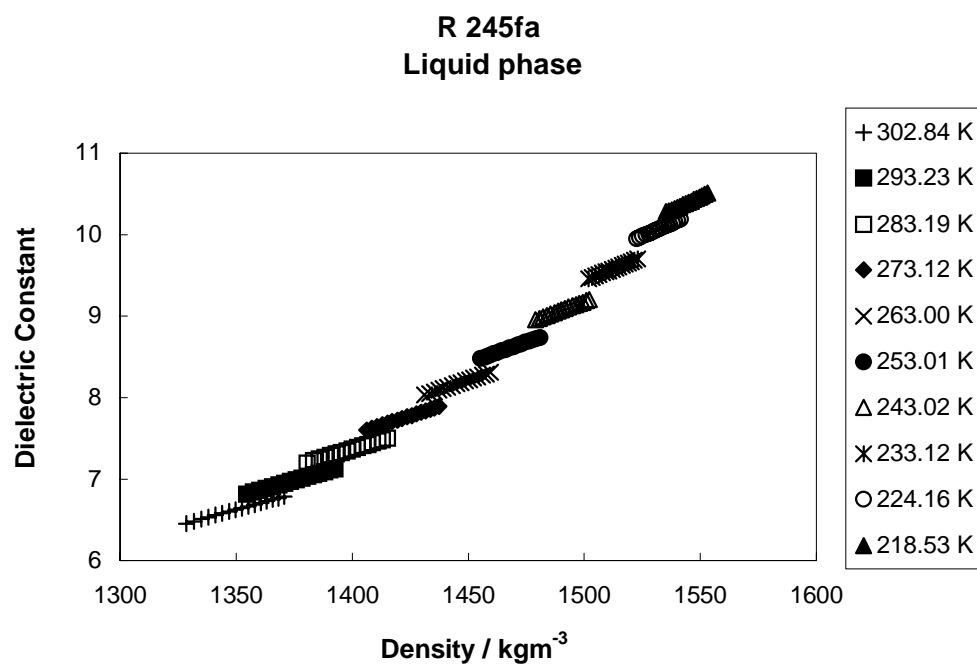


Figure 4. Variation of Δ with the Eulerian Strain, Σ (eq.5).

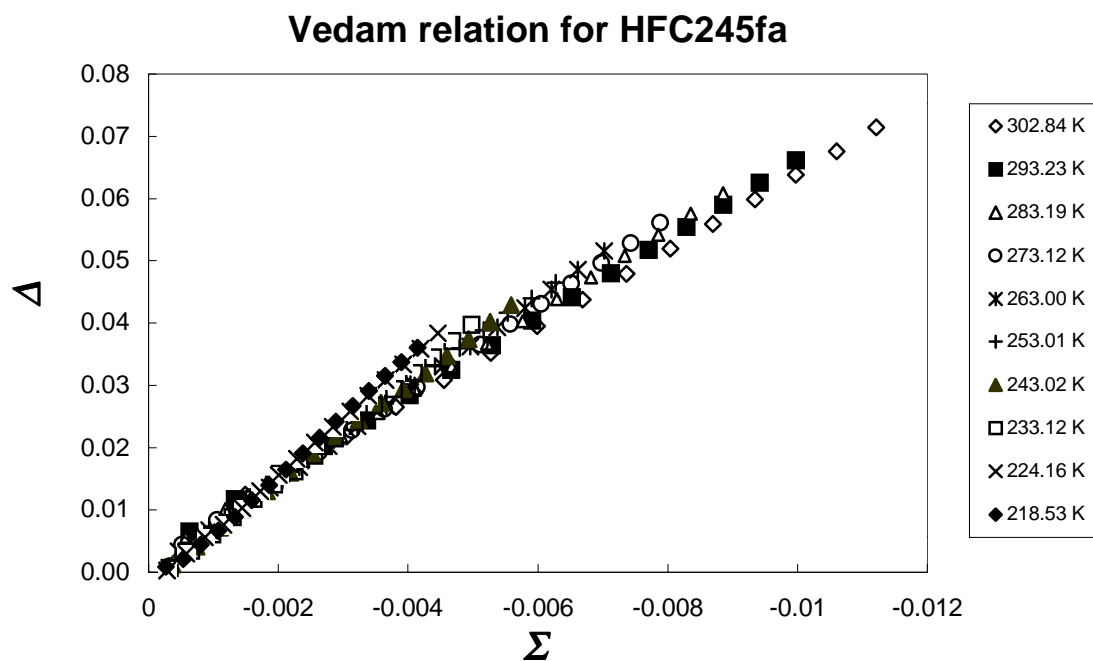


Figure 5. Deviations from the experimental data of the dielectric constant values $[(\epsilon_{VR} - \epsilon_{exp}) / \epsilon_{exp} * 100]$, according to the Vedam relation (eq.7).

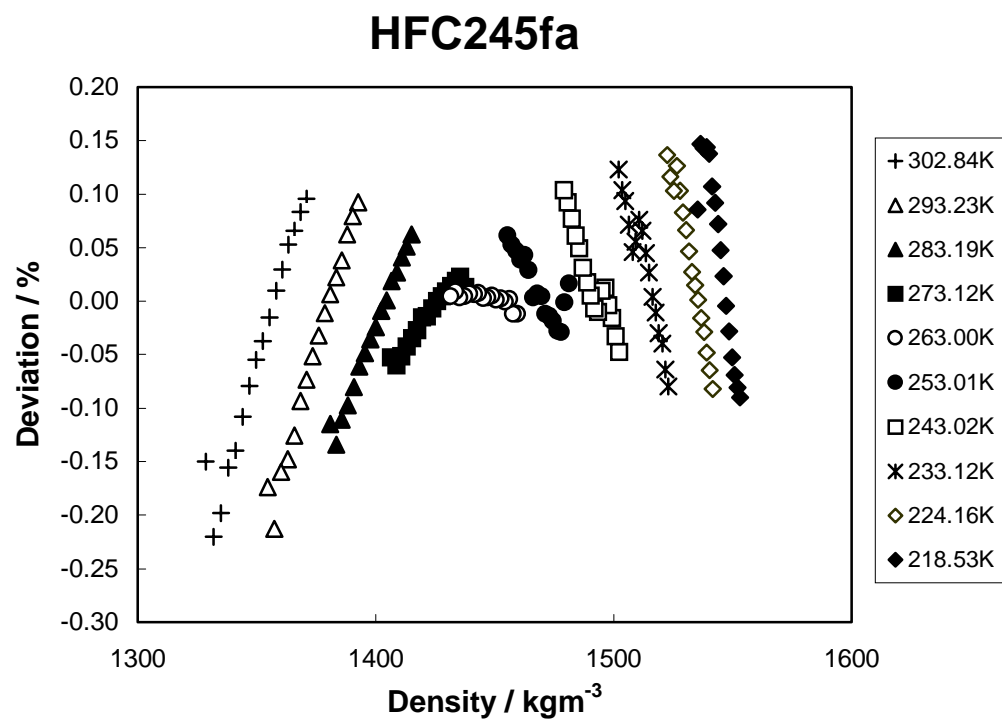


Figure 6. Kirkwood function vs. $1/T$.

